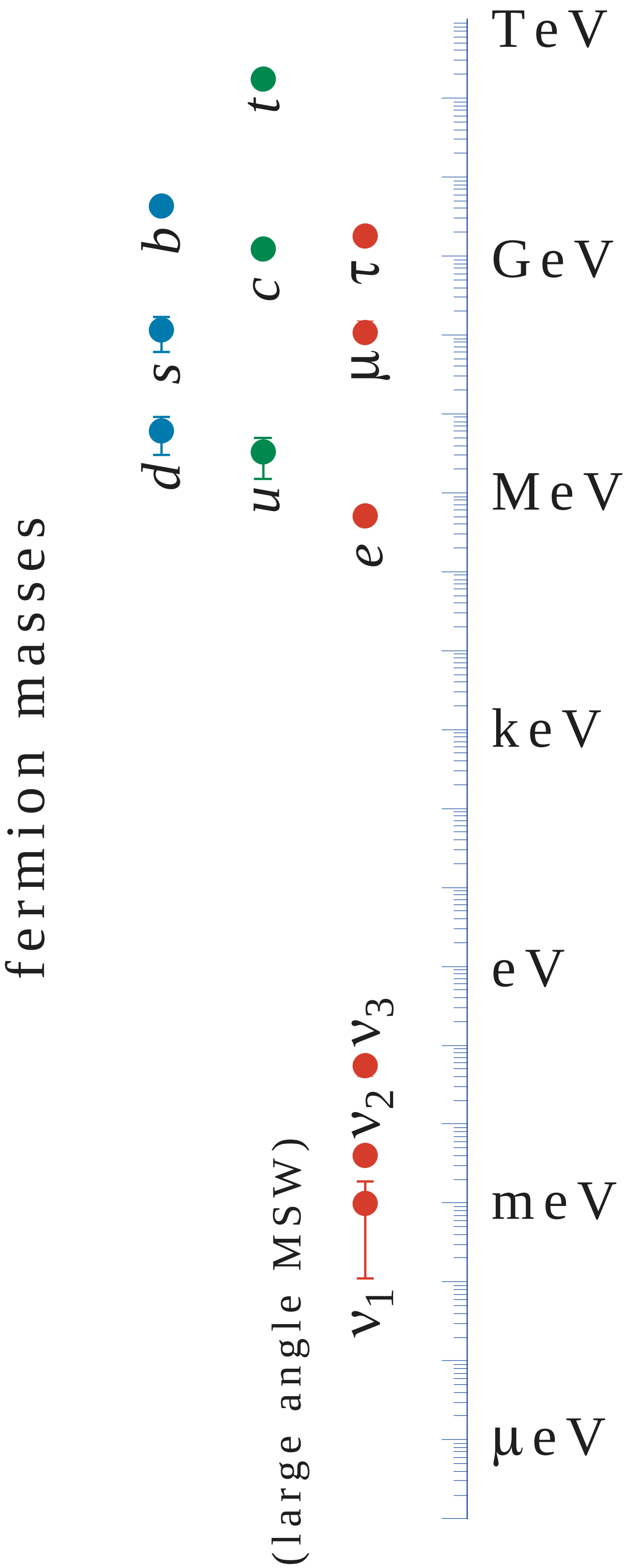
Akira KONAKA
TRIUMF
September 21, 2002
@TRIUMF 5YP town hall meeting

The JHF-Kamioka neutrino project

- Roadmap of the neutrino physics
- The JHF-Kamioka project
- Long baseline neutrino activities in Canada
- TRIUMF experties and possible contributions
- Summary



fermion masses
TeV
GeV
MeV
keV
eV
meV
μeV
t
b
c
τ
s
μ
d
u
e
ν3
ν2
ν1
(large angle MSW)

Impact of the discovery of neutrino mass

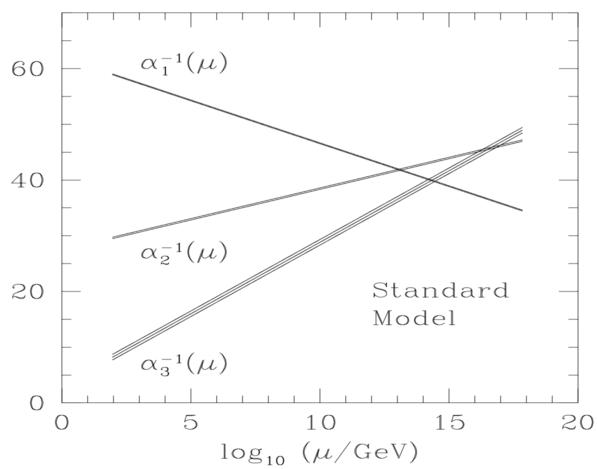
- **Small ν mass $\rightarrow$ new physics scale**

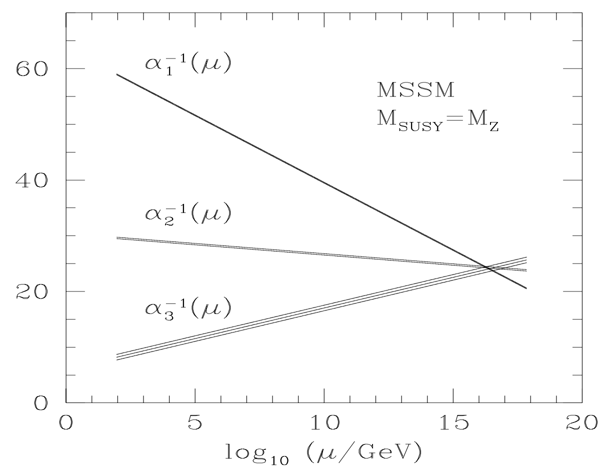
$$\frac{m_{\nu_3}}{m_\tau} = \frac{\sqrt{3\times 10^{-3} eV^2}}{1.3 GeV} = 4\times 10^{-11}$$

$\Rightarrow$ Grand Unification and/or extra dimensions

- **Grand Unification (GUT)**

Gauge Unification at $10^{16} GeV$





Baryon asymmetry of the universe

$\Rightarrow$ Majorana neutrino decay in GUT(Leptogenesis)

- **Extra dimensions in space-time (string theory)**

Gravity and quantum mechanics $\Rightarrow$ extra dimensions (string)

Grand Unification and neutrinos

- See-saw mechanism

Majorana mass: ν_R is GUT singlet $\Rightarrow M_R \sim M_{GUT}$

Dirac mass: $m_D \nu_L \nu_R$ by Higgs $\Rightarrow m_D \sim v = 250 GeV$

$$\begin{pmatrix} \nu_L & \nu_R \end{pmatrix} \begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix} \overset{\text{diagonilize}}{\Rightarrow} \qquad m_\nu = \frac{m_D^2}{M_R}$$

$$m_\nu^2 = 3 \times 10^{-3} \Rightarrow M_{GUT} \sim M_R = \frac{m_D^2}{m_\nu} \sim 5 \times 10^{15} GeV$$

Consistent with the Gauge unification!

- **GUT** explored by neutrinos

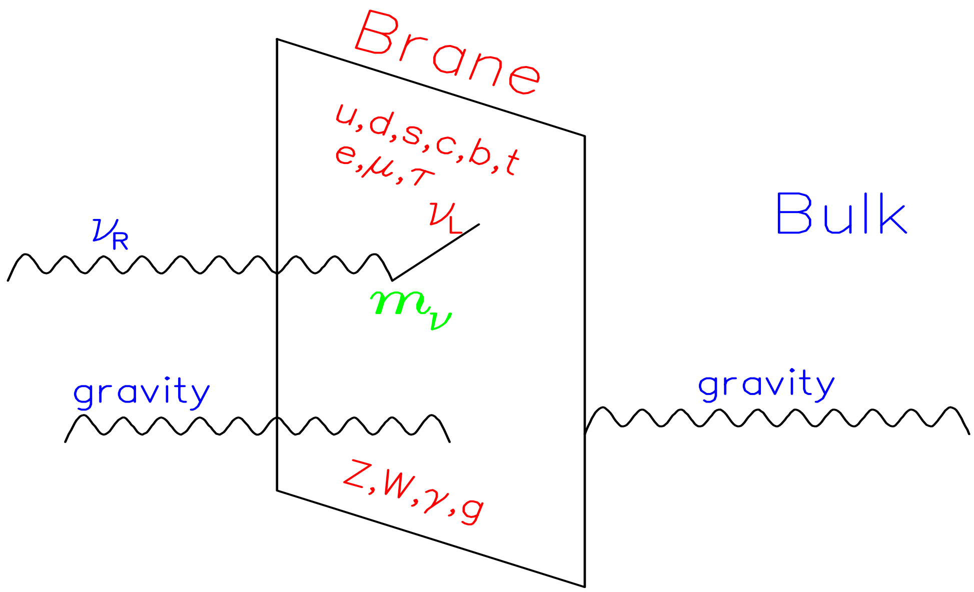
  - ν mass $\Rightarrow M_R$: energy scale of GUT
  - CP violation $\Rightarrow$ Leptogenesis

Extra-dimensions and neutrinos

- **Extra Dimensions** implied by ν mass

  ν_R(singlet) in the bulk space

  $\Rightarrow$ small overlap between ν_R and $\nu_L \equiv$ small ν mass



- **Extra dimensions** explored by neutrinos

  - **Oscillation pattern** $\equiv$ interaction between ν_R and ν_L

    Explore extra-dimensional space by neutrino oscillation

  - **CPT violation:** $\Delta m_\nu \neq \Delta m_{\bar{\nu}}$**?**

    $\Leftarrow$ Due to break down of Lorenz invariance?

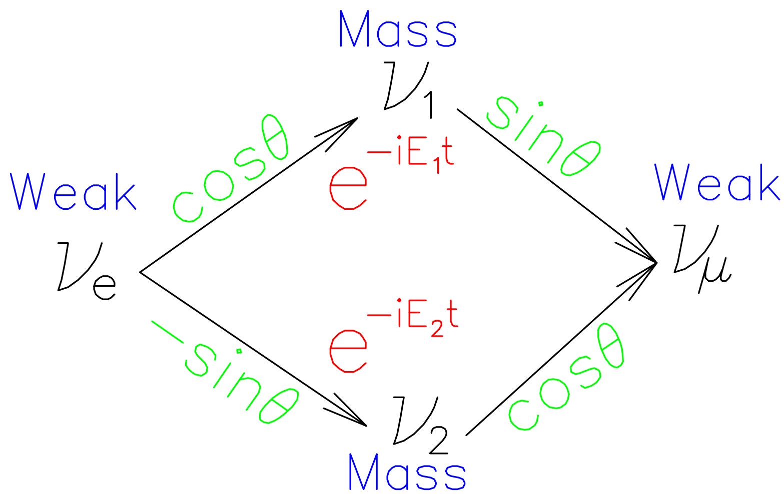
  - **Sterile neutrinos (K-K mode)?**

    $\Rightarrow$ Comparison between NC and CC, Unitarity test

Physics of neutrino oscillations

- **Neutrino oscillation in 2 generations**

$$\begin{pmatrix} U_{e1} & U_{e2} \\ U_{\mu 1} & U_{\mu 2} \end{pmatrix} = \begin{pmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{pmatrix}$$



$$\begin{aligned} P(\nu_e \rightarrow \nu_\mu) &= |sin\theta cos\theta(e^{-iE_1 t} - e^{-iE_2 t})|^2 \\ &= sin^2 2\theta sin^2 \frac{1.27\Delta m^2 L(km)}{E(GeV)} \end{aligned}$$

	$\Delta m^2 (eV^2)$	L(km)/E(GeV)
Atmospheric	$\sim 3 \times 10^{-3}$	1300
Solar (LMA)	$\sim 5 \times 10^{-5}$	10^5
LSND	~ 1	4

3 generation effect

• Lepton mixing matrix (MNS matrix)

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

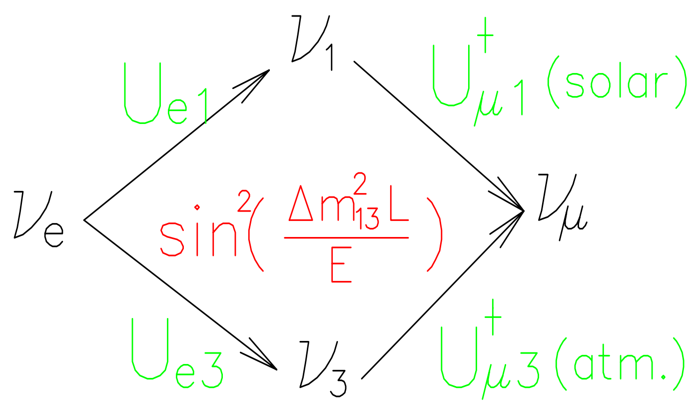
Leptonic CKM
(MNS matrix)

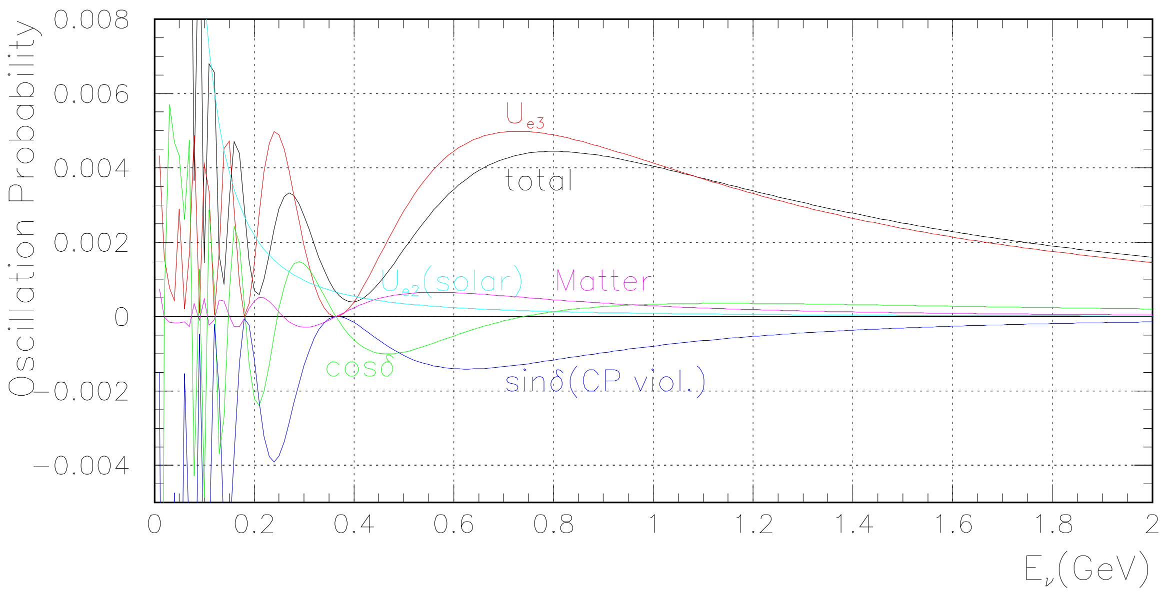
$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & e^{i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric *New* *Solar*

• Golden neutrino oscillation mode

$\nu_e \leftrightarrow \nu_\mu$ is suppressed
due to small Δm^2_{12}
$\Delta m^2_{13}(\theta_{13})$ dominates
Large CP contribution





“Road-map” of Neutrino oscillations

1. LSND: $\bar{\nu}_\mu \to \bar{\nu}_e$ at $\Delta m^2 \sim 1eV^2$

- **Status:**
  - LSND-DAR: $P = (0.264 \pm 0.067 \pm 0.045)\%$
  - KARMEN: no excess, some parameter space left.
  - Beyond 3 generation MNS matrix: CPT violation?

- **Next Step:** mini-BooNE (June, 02)

  (a) mini-BooNE $(\nu_\mu, \bar{\nu}_\mu)$ does not see the oscillation
  $\Rightarrow$ the case closed

  (b) Surprise: mini-BooNE does see the oscillation
  $\Rightarrow$ Follow-up experiments to study this.

2. $\Delta m_{12}, \theta_{12}$: Solar

- **Status:**
  - – Deficit is observed by Ga, Cl, H_2O, D_2O experiments
  - – Flavor oscillation is confirmed by SNO ($> 5\sigma$)
  - – LMA is favoured (99.5%CL)

- **Next Step:** KamLAND:reactor $\bar{\nu}_e \to \bar{\nu}_\mu$ (Jan. 02)

(a) KamLAND confirms LMA signal
  $\Rightarrow$ Precise oscill. pattern measurement (KamLAND)
  $\Rightarrow$ Spectral distortion in LMA (^7Be: Borexino,KamLAND)
  $\Rightarrow$ Study of the solar model (^7Be, p-p neutrinos)

(b) Surprise:KamLAND do not see oscillation
  $\Rightarrow$ ^7Be: Borexino,KamLAND

3. $\Delta m_{23}, \theta_{23}$: Atmospheric

- **Status:**
  - Deficit up/down asymm. observed by Super-K
  - Consistent with $\nu_\mu \to \nu_\tau$ (Super-K)
  - Confirmed (99.3%CL) by K2K-I
  - Oscillation pattern seen at 85%CL (K2K-I)

- **Next Step:**

  ν_μ disappearance: K2K-II(Nov. 02)/MINOS(2005)
  $\nu_\mu \to \nu_\tau$ appearance: ICARUS/OPERA(2006)

  (a) Confirmation of the SK/K2K-I results
  $\Rightarrow$ Precision test of the oscillation framework
  oscill. pattern, NC/CC, CPT $\Leftarrow$ **JHF-SK(2007)**

  (b) Surprise:Disagreement with SK/K2K-I
  $\Rightarrow$ Precise and high statistics $\Leftarrow$ **JHF-SK**

4. $\Delta m_{13}, \theta_{13}$: **"The next step"**

- **Status:**
  Reactor ν_e disappearance (CHOOZ): $\sin^2 2\theta_{13} < 0.1$

- **Nest step:**
  $\nu_\mu \to \nu_e$ appearance (**JHF-SK**,NuMI off-axis)

- **Future:**
  - CP High intensity/large detector
    JHF-HyperK, and similar ones in US/Europe
  - Matter effect: Very long baseline
    JHF-Korea, BNL-Homestake, FNAL-SK

- **Further down the road:**
  Neutrino factory, β neutrino beam

Letter of Intent: June 5, 2001 (hep-ex/0106019)

The JHF-Kamioka neutrino project

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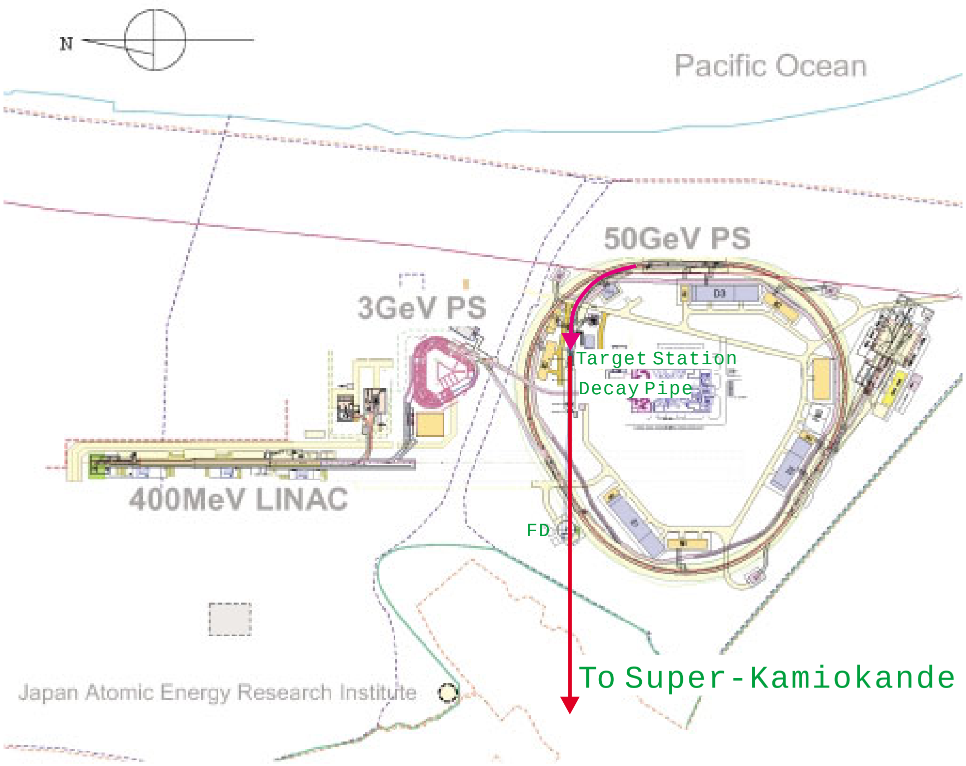
Abstract

The JHF-Kamioka neutrino project is a second generation long base line neutrino oscillation experiment that probes physics beyond the Standard Model by high precision measurements of the neutrino masses and mixing. A high intensity narrow band neutrino beam is produced by secondary pions created by a high intensity proton synchrotron at JHF (JAERI). The neutrino energy is tuned to the oscillation maximum at ∼1 GeV for a baseline length of 295 km towards the world largest water Čerenkov detector, Super-Kamiokande. Its excellent energy resolution and particle identification enable the reconstruction of the initial neutrino energy, which is compared with the narrow band neutrino energy, through the quasi-elastic interaction. The physics goal of the first phase is an order of magnitude better precision in the $\nu_\mu \to \nu_\tau$ oscillation measurement ($\delta(\Delta m^2_{23}) = 10^{-4}$ eV^2 and $\delta(\sin^2 2\theta_{23}) = 0.01$), a factor of 20 more sensitive search in the $\nu_\mu \to \nu_e$ appearance ($\sin^2 2\theta_{\mu e} \simeq 0.5 \sin^2 2\theta_{13} > 0.003$), and a confirmation of the $\nu_\mu \to \nu_\tau$ oscillation or discovery of sterile neutrinos by detecting the neutral current events. In the second phase, an upgrade of the accelerator from 0.75 MW to 4 MW in beam power and the construction of 1 Mt Hyper-Kamiokande detector at Kamioka site are envisaged. Another order of magnitude improvement in the $\nu_\mu \to \nu_e$ oscillation sensitivity, a sensitive search of the CP violation in the lepton sector (CP phase δ down to $10^\circ - 20^\circ$), and an order of magnitude improvement in the proton decay sensitivity is also expected.

The JHF project

JAERI@Tokai (60km N.E. of KEK)

Under construction: Beam commissioning in 2006



	JHF	MINOS	K2K
E(GeV)	50	120	12
Intensity (10^{12}ppp)	330	40	6
Rate (Hz)	0.292	0.53	0.45
Power (MW)	0.77	0.41	0.0052

10^{21}POT/year

Beam power is anticipated to be upgraded up to 4MW (upgrades in RF/power supplies and the barrier bucket scheme)

Principles of the JHF-Kamioka project

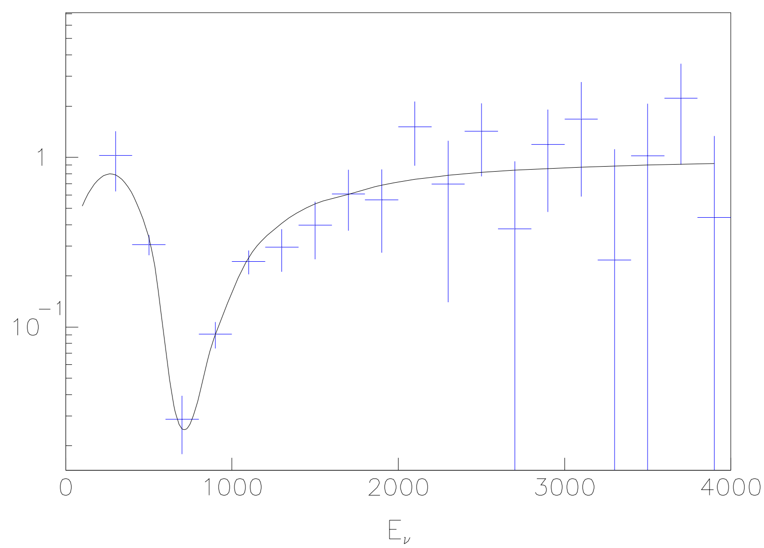
Discovery of Z^0 (SPS)
$\Rightarrow$ Precision measurements of EW int. at Z^0 pole (LEP)
Discovery of ν oscillation (Super-Kamiokande)
$\Rightarrow$ Precision measurements of ν oscil. at oscil. max.

- The highest intensity proton accelerator; JHF
- The largest water Čerenkov detector; Super-Kamiokande
  Excellent for $E_\nu < 1GeV$
- Narrow band beam at oscillation max; Off-axis beam
  L=300km $\Rightarrow$ E_ν=(0.4-1.0)GeV
- Reconstruction of the neutrino energy; QE reaction
  Works best for $0.5GeV < E_\nu < 1GeV$

ν_μ disappearance

Physics goal: **Test of the oscillation framework**

- **Precise oscillation pattern study**



– Does ν_μ disappearance follow the oscillation curve?
Sterile? Extra dimension? New interactions?

– Precision measurement of θ_{23} and Δm^2_{23}
$\sin^2 2\theta_{23} < 1$? $\sin^2 2\theta_{23} = 1$??, or $\sin^2 2\theta_{23} > 1$???

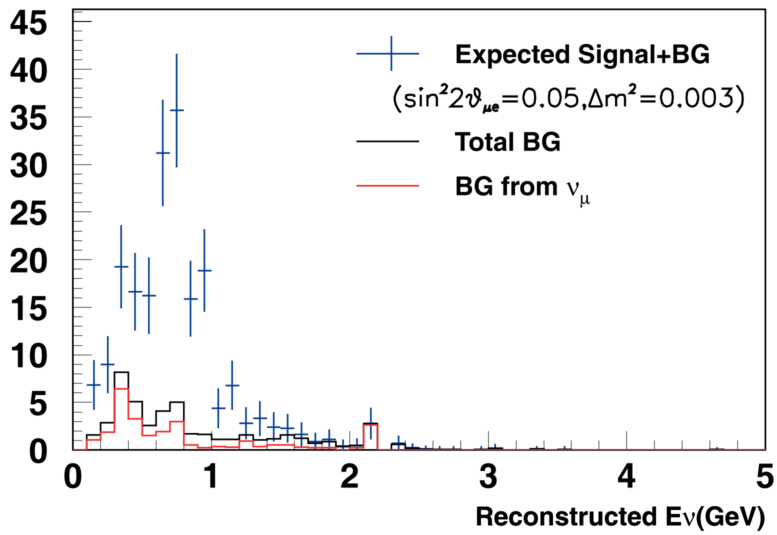
– Comparison of θ_{23} and Δm^2_{23} between ν_μ and $\bar{\nu}_\mu$ (CPT)

– NC/CC ratio: Admixture of sterile neutrinos?

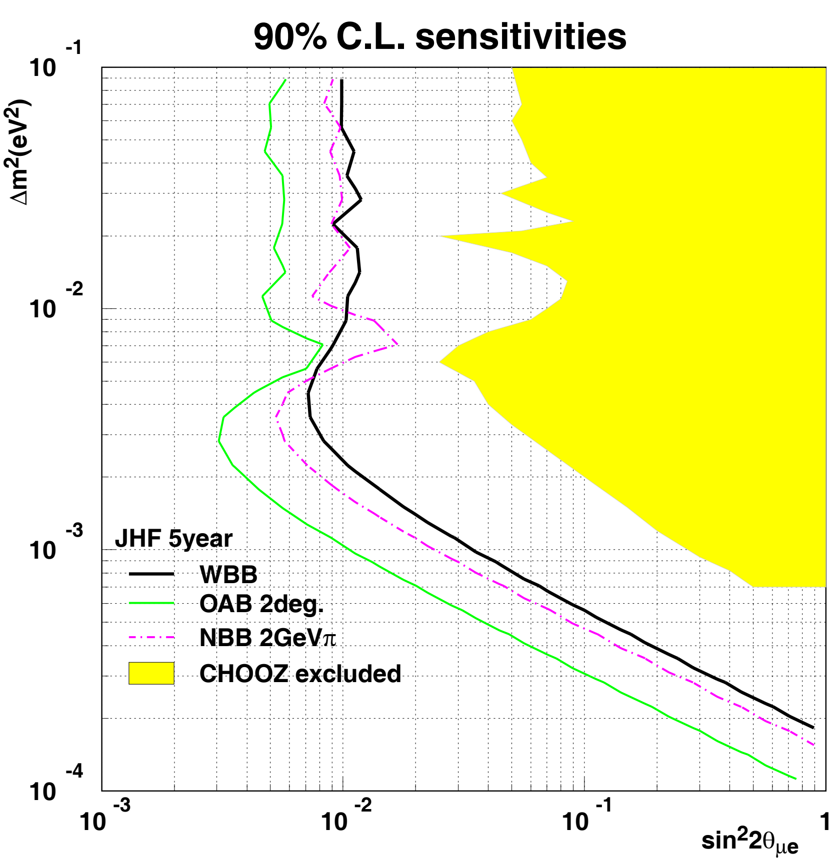
Neutrino oscillation has been presenting surprises
An excellent place to hunt for new physics

$\nu_\mu \to \nu_e$ appearance (U_{e3})

- **Signal**: $\nu_e(\text{far})/\nu_\mu(\text{near})$
  Expected to appear at the ν_μ disappearance dip.



- Sensitive to $\sin^2 2\theta_{\mu e} > 0.003$



Future of JHF-Kamioka

- Hyper-Kamiokande detector (The 2nd phase)
  - Water Čerenkov technology allows 1Mton detector
  - Extend $\sin^2 2\theta_{13}$ down to 10^{-3}
  - CP violation measurement for $\delta_{CP} > 20^\circ$
  - $\times 10$ better sensitivity in proton decay
  - Detector site identified and R&D started

Prospects

2000 –

- JHF project approved (December)

2001 –

- JHF construction started (April)
- Release of the Letter of Intent (hep-ex/0106019)
  Conceptual design of the JHF-Kamioka project

2002 –

- International JHF-SK meeting (March)
- Grant request of the ν beamline (June)
  $\Rightarrow$ approval expected in Dec.2002 or 2003
- Proto-collaboration meeting (September 26-29)
- Civil construction of the ν-beamline starts (October)
- Updted LOI (December)

2006 –

- Comissioning of the JHF accelerator

2007 –

- Start taking data of the first phase of JHF-SK

Participating institutions at JHF-SK meeting in Kyoto on March 9, 2002

- **Japan**

  ICRR, KEK, Kyoto, Tokyo
- **Korea**

  Seoul, Chonnam
- **Canada**

  TRIUMF
- **US**

  Argonne, Boston, Fermilab, Los Alamos, Pennsylvania,
  Rochester, StonyBrook UC Berkeley/LBNL, UC Irvine, Washington
- **France**

  Lyon, Saclay
- **Italy**

  Napoli, Rome, Padova
- **Switzerland**

  Geneva
- **UK**

  Ratherford-Sussex

Physics Opportunities

- ν_μ disappearance: search for physics beyond MNS
  - Precise measurement of the oscillation pattern
  - NC/CC ratio (sterile neutrino search)
  - CPT (ν_μ vs. $\bar{\nu}_\mu$ disappearanves
- ν_e appearance: $\theta_{13} \Rightarrow$ CP,Matter effect
- Precision measurement of ν-nucleon/nucleus scattering
  - ν cross sections for ν oscillation and proton decay
  - Weak form factors (strangeness in nucleon)
  - Nuclear/hadron physics
- Super-Kamiokande physics
  - Solar neutrinos
  - Atmospheric neutrinos
  - Supernova neutirnos
  - Proton decays
- Short baseline experiment with 2km detector
  (If mini-BooNE confirms LSND results)
- K2K physics

Interests in the community

- **“High priority” rating in the LRPC report**
- **“Workshop on future opportunities in ν physics”**

  $\Rightarrow$ Long baseline ν working group formed ($\sim$30 members)

  $\Rightarrow$ NSERC-IOF grant awarded

  $\Rightarrow$ NSERC grant request for the JHF-SK near detector R&D
- **US Long range plan report to HEPAP**

  The JHF is likely to be the first step in an international program of superbeam facilities...
- **One of the 4 major topics at the ICFA seminar**
  - Neutrino, Linear collider, Hadron collider, Particle Astrophysics
- **JHF-SK inspired efforts around the world**
  - Fermilab: NuMI off-axis beam
  - BNL: Off-axis beam to Homestake off-axis beam
  - CERN: Off-axis beam to Italy

Activity of the neutrino working group

- “High Priority” rating by the FYPC
- “Workshop on future opportunities in neutrino physics”
- Working group formed in Dec. 2001
- Bi-weekly video/phone meetings and Email discussions
  - http://nu.triumf.ca
  - Initial R&D discussion on JHF ν beam
  - Simulation studies of JHF-SK and NuMI off-axis
  - NSERC-IOF grant awarded for travel and workshops
- International JHF-SK meeting in March in Kyoto
- Future NuMI workshop on May2-4
- First internal workshop on May 6 at York university
  JHF-SK selected as the priority
- Long baseline neutrino meeting at CAP on June 3
- The second internal workshop on July 30-31
- JHF-SK proto-collaboration meeting on Sept.26-29
- NSERC grant request on the near detector R&D
- The third internal workshop in winter 2002

List of members

- Peter Kitching[1,3,4] (Alberta)
- John Mcdonald[1,4] (Alberta)
- Jim Pinfold[1,2] (Alberta)
- Manuella Vincter[1,2,3,4] (Alberta)
- Ian Lawson[1] (Guelph)
- David Hanna[1] (McGill)
- Tony Noble[1,2,3] (Queens)
- Roman Tacik[1,4] (Regina/TRIUMF)
- John Martin[1,2,3] (Toronto)
- Pierre Savard[1] (Toronto)
- Garry Levman[1] (Toronto)
- Mike Barnes[3] (TRIUMF)
- Ewart Blackmore[1,3] (TRIUMF)
- Jaap Doornbos[1,2,3,4] (TRIUMF)
- Peter Gumplinger[1,3] (TRIUMF)
- Rich Helmer[1,2,3,4] (TRIUMF)
- Robert Henderson[4] (TRIUMF)
- Fred Jones[1] (TRIUMF)
- Akira Konaka[1,2,3,4] (TRIUMF)
- Glen Marshal[1,2,3] (TRIUMF)
- John Macdonald[1,3] (TRIUMF)
- Chris Nell[1] (TRIUMF)
- John Ng[1,2] (TRIUMF)
- Art Olin[1,2] (TRIUMF)
- Marcello Pavan[1] (TRIUMF)
- Jean-Michael Poutissou[1,2,3,4](TRIUMF)
- Gary Wait[3] (TRIUMF)
- Stan Yen[1,3,4] (TRIUMF)
- Bob Kowalewski[1,3] (Victoria)
- Sampa Bhadra[1,2,3,4] (York)
- Scott Menary[1,2,3] (York)

The numbers indicate that the person is on the following member list:

1. Subscribers of the Canadian long baseline neutrino group
2. Grantee of the international opportunity funds
3. Member of the JHF-SK proto-collaboration
4. Co-applicants of this NSERC SAP Project Research Grant

Canadian JHF-SK activities

- Invention of the off-axis beam idea (E889)
- Founding member of the JHF-SK project
  * ν_e appearance analysis
  * Introduction of the off-axis beam and simulation
  * CP violation study
- Simulation analyses
  * Near detector designs
  * Optimization of the horn
- Facility contributions: model for int. contribution
  * Primary beam optics design
  * Novel dual kicker concept
  * 50GeV accelerator leader's visit in March & September
    - R&D of the kicker (semiconductor switch)
    - R&D of the beam dynamics
  * Hope to provide 1/3 of foreign contribution ($50M/3)
    to maintain the foreign leadership role

Kicker/abort

- No fast abort in the original design (Urgent problem)
  - A novel dual abort kicker concept (TRIUMF,KEK)
  - Dual kicker will be constructed in 2004
- High power semiconductor switch
  - Essential in preventing spontaneous mis-firing
  - General interests in replacing thyratron (e.g. LC)
- Proposal by KEK to form a kicker R&D collaboration
  - Kicker design in FY2002-3 by KEK and TRIUMF
  - R&D of the switch at TRIUMF in FY2003
    R&D equipments to be funded by KEK
  - Construction in FY2004 in Japan
  - Test of the kicker elements in FY2004-5 at KEK and TRIUMF
  - Construction of the spare and upgrade kickers in FY2005-7
  - The collaboration beyond R&D is contingent upon fundings of the neutrino beamline and the TRIUMF 5year plan
- Cost and man power
  - Total kicker capital cost: \$23M $\Rightarrow$ TRIUMF share $\sim$ \$11.5M
  - TRIUMF share could be paid by
    - Funding the spare and upgrade kicker magnets
    - Funding nomal conducting magnets for the ν beam line

Beam pick-up/damper

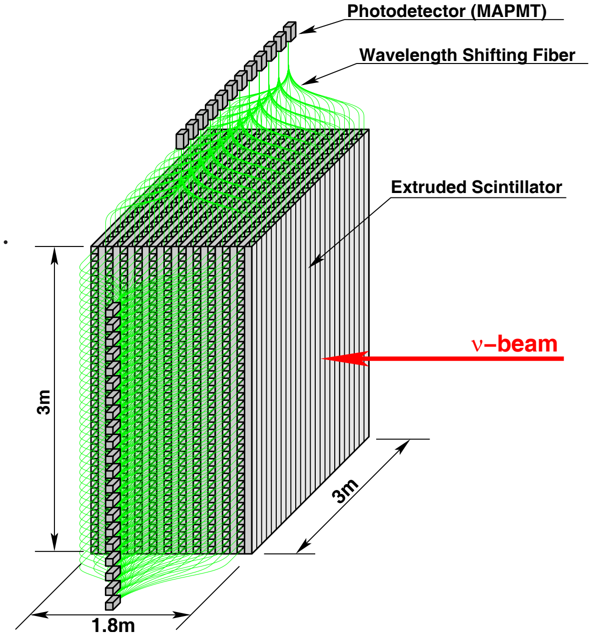
- Feed-back and correct beam instability
  Essential in achieving high intensity beam
- TRIUMF's experties in constructing the system:
  - Beam dynamics
  - Damper RF
  - Beam pick-up monitor
- Proposal by KEK to form a beam dynamics R&D collab.
  - Beam dynamics study of JHF in FY2002-3
  - Design study of the dumper system in FY2003-5
    R&D to be supported by KEK
  - Accelerator study and experiment in FY2006
  - Construction of the damper system in FY2006-7 by TRIUMF
  - TRIUMF to be involved in further intensity upgrades
    Higher repetition rate and injection manipulation
  - The collaboration beyond R&D is contingent upon fundings of the neutrino beamline and the TRIUMF 5year plan
- Cost and schedule
  - Cost of the damper system ∼1M (2005-7)
  - Future intensity upgrade contributions ∼$1M (2008-9)

Primary beamline and shielding

- Impacts on the initial design studies
  - Initial beamline design studies by Doornbos
  - Scraper design studies important for SC magnets
  - Design studies of a 30GeV beamline
- Possible designing/consultation contributions
  - Shielding and handling of rad. hard elements
  - Target/horn design (E889-TRIUMF horn design)
- Contribution to the neutrino beamline magnets
  - 20 Q's (12kG,1.6m) and 20 B's (20kG,3.6m) in the arc
  - To be designed by KEK and constructed in Canada
  - Capital share of the kicker contribution

Near detector R&D and construction

- Fine grained calorimeter
  - NSERC grant request for R&D
  - Optimization of the detector config.
  - Extruded scintillator+shifter fiber
  - Photon readout system
  - Mechanical design



- Contributions expected from TRIUMF
  - Detector development and construction facility (LADD)
  - DAQ/Electronics and detector groups
  - Suport for the engineering design
  - Beam test at TRIUMF
- Physics impacts
  - Detailed measurements of the CC and NC cross sections
  - Understand backgrounds for $\nu_\mu \rightarrow \nu_e$ appearance
  - Estimate the normalization factor (Far/Near ratio)
  - Background study for proton decay
- Cost and scheudle
  - Schedule: 2003(R&D), 2004-6(construction)
  - Cost: ~\$5-10M (NSERC)

Item	FY2003	FY2004	FY2005	FY2006	FY2007	FY2008	FY2009
Kicker	1.0FTE	1.0FTE	1.0FTE	1.0FTE	1.0FTE	1.0FTE	0
	0	0	$0.5M	$1.0M	$1.0M	$0.5M	0
	R&D and test		tests	Upgrade/spare construction			
Neutrino magnets	0.1FTE	0.1FTE	0.5FTE	0.5FTE	0	0	0
	0	0	$3.5M	$3.5M	0	0	0
	Design by KEK		Construction				
Beam dynamics	0.5FTE	0.5FTE	2.0FTE	3.5FTE	3.5FTE	3.0FTE	3.0FTE
	0	0	$0.1M	$0.3M	$0.6M	$0.5M	$0.5M
	R&D and design			study/construction		upgrades	
Total	1.6FTE	1.6FTE	3.5FTE	5.0FTE	4.5FTE	4.0FTE	3.0FTE
	0	0	$4.1M	$4.8M	$1.6M	$1.0M	$0.5M

- R&D costs for the kicker and beam dynamics (damper system) in FY2003-4 would be supplied by KEK.
- Kicker man power includes contributions from students
- Neutrino magnets would be designed by KEK in consultation with TRIUMF

Item	FY2003	FY2004	FY2005	FY2006	FY2007	FY2008	FY2009
Near detector	0.5FTE	2.0FTE	1.5FTE	1.0FTE	1.0FTE	0.5FTE	0.5FTE
	0	$0.1M	$0.1M	$0.1M	0	0	0
	R&D	design/construction				upgrades	

- Detector R&D and construction cost is anticipated from NSERC
- Infrastructure support from LADD is anticipated
- TRIUMF contribution to part of the construction man power anticipated
- Support from NSERC infrastructure grant at Alberta is anticipated (subject to funding)

Summary

1. **Neutrino oscillation, one of the few main future**
   - Identified by Canadian 5-year plan, HEPAP, ICFA, etc.
   - Active field with new exciting results every few months
   - The roadmap is clear: $\theta_{13} \rightarrow CP$ with superbeam
   - Strong appeal to the public and students
2. **JHF-Kamioka project is the front runner**
   - Right neutrino energy (0.5-1.0GeV) and distance (300km)
   - Identified by the Canadian neutrino working group
   - Recognized by the international community
   - Funding of ν beamline expected in Dec. 2002 or 2003

3. **Canadian visibility**

- Japan (SuperK) and Canada (SNO) lead the field
- Order of magnitude smaller than collider experiments
  $\Rightarrow$ Bigger impact by the Canadian group
- Canadians have been involved from the very beginning
  - Off-axis beam idea
  - ν_e appearance analysis
  - CP violation study
  - Primary beam transport and dual abort kicker

4. **Excellent candidate for the TRIUMF 5-year plan**

- Excellent and timely physics opportunity
- Good match with TRIUMF experties
- Support from Canadian subatomic physics community
- Highly visible and appealing to the public and students